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OF THE
EXPERIMENT STATION
OF THE
HAWAIIAN SUGAR PLANTERS' ASSOCIATION

ENTOMOLOGICAL SERIES
BULLETIN NO. 17

# The Field Rat in Hawaii and Its Control

IMPERIAL BUREAU
27 JUL 1925

By C. E. PEMBERTON

HONOLULU, HAWAII
June, 1925

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By C. E. PEMBERTON

HONOLULU, HAWAII
June, 1925

## LETTER OF TRANSMITTAL

*To the Experiment Station Committee*
*of the Hawaiian Sugar Planters' Association,*
*Honolulu, T. H.*

Gentlemen:

I submit herewith for publication, as Bulletin No. 17 of the Entomological Series, a paper by C. E. Pemberton, entitled: *The Field Rat in Hawaii and Its Control.*

Yours very truly,

H. P. AGEE,
Director.

Honolulu, T. H.,
April 27, 1925.

Honolulu, T. H., March 26, 1925.

*The Director,*
*Experiment Station, H. S. P. A.,*
*Honolulu, T. H.*

Dear Sir:

I submit herewith for transmission to the Experiment Station Committee, a report by C. E. Pemberton on his work of checking up the results of the rat control campaign since 1922, initiated by the Honokaa Sugar Company and Pacific Sugar Mill on Hawaii.

This report deals mostly with the work done by W. P. Naquin, Manager of Honokaa Sugar Company and Pacific Sugar Mill, on rat control. This work was started in 1918 when careful counts showed that between 30 and 40 per cent of the stalks of sugar cane were attacked by rats. This high percentage of damaged stalks indicated that neither the mongoose nor the rat-catching then carried on was sufficient to keep this pest within economic limits. Mr. Naquin therefore decided to start an intensive campaign of poisoning. During 1919 and 1920 most of the commercial rat poisons on the market were tried. These, although efficient as poisons, were too expensive for application on such a large scale. Moreover, they all deteriorated very quickly under field conditions, moisture soon spoiling them as bait. In 1920, efforts were made to protect the individual baits of barium carbonate by coating them with a thin layer of paraffin. This was eminently successful. As experiments showed that all rats did not take these paraffin-coated cakes of barium carbonate, small packages, or torpedoes, of strychnine-covered wheat were used. These cakes and torpedoes were distributed systematically in great numbers.

Wishing to have the work checked up and systematic observations made so as to be sure that the desired results were obtained, Mr. Naquin, in 1923, requested the Experiment Station to allow one of the staff to reside in the Honokaa district for a time and follow the work done. Mr. Pemberton was assigned to this work, which he deals with in his report. This report shows that Mr. Naquin has fully accomplished his object in reducing the rat damage to an almost negligible quantity. His methods, with such alterations as local conditions necessitate, as, for instance the selection of the most suitable food for the locality, should have wide application and be a great boon to agriculture.

Besides checking up the rat damage in cane fields, Mr. Pemberton has made valuable observations upon the rat fleas and plague, and the climatic factors which influence them, which should be of value in future plague campaigns in this locality.

Yours very truly,

F. Muir,
Entomologist.

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# The Field Rat in Hawaii and Its Control

By C. E. Pemberton

Since the introduction of an intensive study of the rat problem in the cane fields of Hawaii in 1922, several advance reports have been published in *The Hawaiian Planters' Record,* giving the results of progress for the immediate benefit of those interested. This investigation, followed continuously for two and one-half years, has advanced so far that definite conclusions have been reached. Some of the recommendations presented in the early reports have been modified and better details of procedure have evolved. The present paper is prepared as a brief compilation of the preliminary reports, together with the embodiment of further details in control measures and should prove useful to any planter interested in rat repression.

The problem is not completely solved, but the results have been so positive, so economically successful, that we have no hesitation in recommending the methods of control herein given.

## History

We are not greatly concerned with the history of rats, but as a matter of general interest a brief sketch is given of what is known historically of the species of rodents present in Hawaii.

When Captain Cook visited Hawaii in 1778, he found a small rat present which the natives called "Iole", and perhaps a mouse. R. C. L. Perkins, in the *Fauna Hawaiiensis,* states that the cosmopolitan house mouse, *Mus musculus* Linn., was at least common in Hawaii by 1825. John F. G. Stokes, Curator of Polynesian Ethnology of the Bishop Museum, Honolulu, found bones of a small rat on the island of Kahoolawe in April, 1913. In May, 1915, he found the same on the sand dunes of Heleloa, Mokapu Peninsula, Oahu, and the same year he found and caught living specimens of this rat on Popoia Islet, Kailua Bay, Oahu, which were described in 1917 by Witmer Stone, of the Philadelphia Academy of Natural Sciences, as *Rattus hawaiiensis* Stone, and it is now considered a native species. Hawaiian chiefs are said to have amused themselves in shooting this rat with bow and arrows. This rat is different from the present introductions and is now rare, having been supplanted by the cosmopolitan species.

In addition to the common house mouse, *Mus musculus* Linn., three definitely recognized rats are known in Hawaii, designated as the black or house rat, *Rattus rattus* (Linn.) ; the Alexandrine rat, *Rattus rattus alexandrinus* (Geoffroy), known as the white-bellied or yellowish-bellied tree or roof rat, which is a sub-species of the black rat; and the brown rat, *Rattus norvegicus* (Erxlelen), variously called the gray rat, wharf rat, sewer rat, migratory rat, or Norway rat. All three are destructive to sugar cane, but more particularly the last named species.

The house mouse seems to have been well known to the ancient Greeks and Romans, reaching the United States at the time of the first European settlement. It is believed to be of Asiatic origin. Authorities generally agree that the black rat had its original home in India and Burma, and the gray rat in temperate Asia.

These rats do not seem to have been known to the ancient Greeks and Romans, but by the Twelfth Century the black rat was known in Europe and accompanied the appearance of devastating plagues. The gray rat seems to have spread more recently, for it was apparently unrecorded in Europe until about 1716. It was known in the United States by 1775, and the black rat by the middle of the Eighteenth Century. Apart from the so-called native Hawaiian rat and the mouse, introduced rats probably did not appear in Hawaii until the Nineteenth Century; how early we do not definitely know, but they no doubt came with some of the first sailing vessels calling here.

## Breeding Habits

Rats are exceedingly prolific, and in warm countries are unusually so. The period of gestation is generally from 21 to 30 days, sexual maturity occurs at the age of 3 or 4 months, a normal litter ranges from 6 to 10 young when food is abundant, and there are usually from 5 to 6 litters per annum. These figures are taken from the findings of several authorities and will fluctuate considerably, depending upon availability of food, varying climatic conditions, and the density of the rodent population. The number of young per litter in the gray rat appears to be a little in excess of that of the black rat.

Young are found at all times of the year in Hawaii. We have no definite data as to their seasonal differences here. Investigators in other countries have found that more litters occur in the spring and summer months than in the colder part of the year. Well-grown females are said to have larger litters than younger individuals. Rats are known to continue growing until about one and one-half years of age.

The ratio of males to females is generally considered about equal.

T. Norman White's report on the variations of sex ratio among rats in India at several localities gives the following data:

| | | |
|---|---|---|
| Lucknow | 16,512 males | 18,396 females |
| Cawnpore | 25,343 " | 25,838 " |
| Banda | 4,953 " | 5,174 " |
| Coimbatore | 1,817 " | 2,072 " |
| Ballia | 1,975 " | 2,550 " |
| Total | 50,600 males | 54,030 females |

In a series of sex examinations by Petrie and Macalister in England in 1911, they record 3,273 males to 2,724 females.

At our suggestion to F. E. Trotter, President of the Board of Health, Territory of Hawaii, C. Charlock, Chief Sanitary Inspector, Island of Hawaii, instituted a series of sex determinations on rats caught on that Island beginning September 1, 1922. The interesting data thus collected from September 1, 1922, to February 28, 1923, are given in Table 1. They show a preponderance of females in each species of rodent, but especially so in the case of the black rat, which showed 63 per cent to be females.

TABLE I

**PROPORTION OF SEXES IN TRAPPED RODENTS ON ISLAND OF HAWAII, FROM SEPTEMBER 1, 1922, TO FEBRUARY 28, 1923**

| | Rattus norvegicus | | Rattus alexandrinus | | Rattus rattus | | Mus musculus | |
|---|---|---|---|---|---|---|---|---|
| | Males | Females | Males | Females | Males | Females | Males | Females |
| September, 1922 | 703 | 1,047 | 475 | 784 | 719 | 1,106 | 2,209 | 3,094 |
| October, 1922 | 663 | 1,043 | 365 | 610 | 986 | 1,551 | 1,948 | 3,272 |
| November, 1922 | 756 | 1,238 | 250 | 405 | 1,206 | 2,107 | 2,678 | 4,988 |
| December, 1922 | 676 | 1,285 | 270 | 513 | 1,188 | 2,331 | 3,265 | 5,072 |
| January, 1923 | 730 | 1,094 | 320 | 503 | 1,346 | 2,490 | 3,177 | 4,708 |
| February, 1923 | 642 | 890 | 326 | 470 | 1,291 | 1,918 | 2,468 | 3,765 |
| TOTAL | 4,170 | 6,597 | 2,006 | 3,285 | 6,736 | 11,503 | 15,745 | 24,899 |

Total Rats—12,912 males 21,385 females.
" Mice—15,745 " 24,899 "

## Food Habits

A list of the foods favored by rats is unnecessary. It would include almost every known food used by man and much in addition.

In cane fields, the bulk of the food is sugar cane usually sufficiently matured to bear a noticeable sugar content. Very young sticks are sometimes eaten, but not so frequently as the sweeter old joints. The principal content of rat excrement found in the fields is cane fiber from the stalk. Insects are also largely eaten. In buildings at Honokaa having accumulations of the mud nests of the Sphecid wasp, *Sceliphron caementarium* (Drury), rats frequently break them up to secure the contained larvae or pupae of the wasp. Grubs of the cane beetle borer are also much eaten by rats, but they do not necessarily attack cane for the contained borer grubs. The sugar cane mealybug, *Pseudococcus sacchari* (Ckll.), which concentrates beneath the cane leaf sheaths, is very extensively eaten by mice, as shown in Fig. 1. Rats no doubt have this habit also. The eaten condition of the leaf sheaths as shown in Fig. 1 is commonly seen in Hawaii.

Grass seeds have been found in rat excrement, and empty seed pods of a common legume, *Crotalaria* sp., and seed burs of a cocklebur, *Xanthium strumarium* Linn., have often been found within the rat burrows underground, though never in quantity, and often from 50 to 100 yards from the source of supply. The seed pods of the pigeon pea, *Cajanus indicus* Spr., are also sometimes favored by rats and mice. Rats are especially fond of the fruits of the screw pine or Pandanus, *Pandanus odoratissimus* Linn., where it grows in dense thickets along the seacoast, as shown in Fig. 2, and up the gulches. Young chickens are sometimes attacked by rats, as well as the eggs and young of birds. Some grasses are eaten, and especially the very common so-called "Honohono" grass, *Commelina nudiflora* Linn., a creeping Commelinaceous plant. Caged rats eat this greedily. Papaia fruits are frequently eaten. Recently we have heard considerable complaint of rats eating the pulp of ripening coffee berries in the Kona district of Hawaii. The list might be continued to include a great variety of foodstuffs both manufactured and in the raw state.

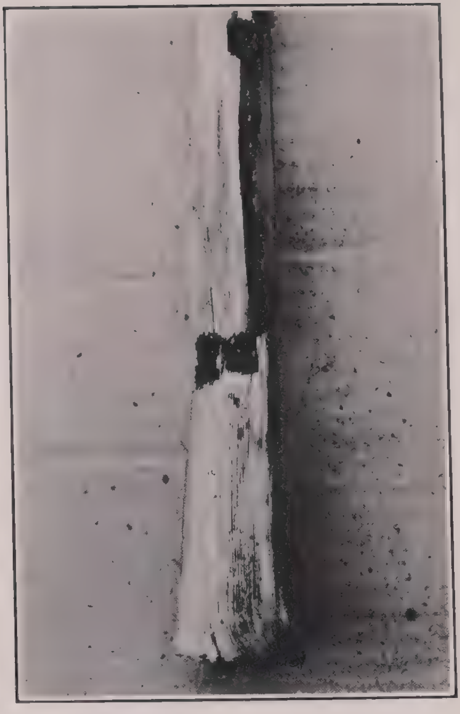


Fig. 1. Cane leaf sheath eaten through by mice to obtain mealybugs lying beneath it.

Fig. 2. Thickets of Pandanus growing along the seacoast of Honokaa Sugar Company, where the field and tree rat feed and colonize extensively.

Though cane would not seem to be a natural food of rats in Hawaii or elsewhere, we must grant that in some parts of Hawaii it is. In Java, where cane and rice are often grown in adjacent areas, rice paddy is much favored by the Javanese field rat, *Mus diardii*, and cane is considered a secondary rat food, becoming primary only after the rice is harvested.

The rapid development of thriving and destructive colonies of rats on some of our cane plantations would indicate that the food ration in such places is well balanced and sufficient until the colonies become very large. Some important element of food, apart from cane, must be present to enable them so to develop, for the cane can, in most part, only satisfy the carbohydrate requirement. The necessary proteid element must be supplied elsewhere. Cane alone is an insufficient food. This has been well proven by E. L. Caum, in experiments recorded in *The Hawaiian Planters' Record,* Vol. XXVI, July, 1922. Mr. Caum fed white rats exclusively on sugar cane for 53 days, when the experiment was terminated. At the termination of the period the rats were greatly emaciated, weak, and had not bred, while the checks remained normal. The factor limiting the increase of rats on cane plantations is the availability of proteid foods. In these fields this must be supplied by insects, other forms of small animal life such as snails, worms, small crustacea, etc., and the seeds of grasses, weeds, shrubs, etc. This being the limiting factor the utilization of poisons carried in proteid media such as grain, flour cakes, etc., enables a poison campaign to succeed when the rat population is large. This is the theory governing the original plan of W. P. Naquin, Manager of Honokaa Sugar Company, in combating rats at this plantation.

The habit of nightly visiting the same spot and feeding is strong. Often cane stools will become much eaten while all adjoining and surrounding stools will remain untouched. The same is true of individual stalks within a stool sometimes. A few joints will be eaten into the first night and several in successive nights thereafter on the same stick. Individual gray as well as black rats often adopt a definite line of travel and follow it each night for a hundred yards or more. Such cases are frequently observed where a rat pursues his nightly course over a series of wires and roofs to some certain building or tree for some mysterious object known only to himself, all of which is strongly indicative that rats may nightly feed several hundred feet from their nests. This has been observed by others.

Rats exhibit great selective power in a choice of foods. Though all varieties of cane grown in Hawaii may become heavily damaged, rats readily select the softer varieties when growing with or near hard varieties.

Though rats feed to some extent during the daylight hours, all evidence points to a strong nocturnal habit in this regard, their eyesight being unquestionably better at night. Poisons and baits put out and examined daily over long periods are nearly always eaten only at night. Mice feed a great deal during the day as well as at night. Heavy rains at night usually prevent much feeding. Poison bait examinations and trapping results have fully shown this.

Though unquestionably endowed with remarkably acute senses of smell, taste, and hearing, in cane fields we see no unusual utilization of these powers in our

warfare with them. There is perhaps no accounting for the choice shown by rats in selecting one food or poison bait over another, if based on our own choice of food by flavor, preferences, or appearances. As already stated, rats may, on occasion, eat anything from soap to our richest and most palatable foods. Certainly some are preferred to others. Respecting taste, the immediate effect upon the body probably governs the extent to which poisons are eaten. Barium carbonate is practically odorless and tasteless, so far as we can judge, yet rats very seldom take much at one time, which suggests their quick recognition of its poisonous effect, rather than the effect of any unpleasant or distasteful flavor. If rats will readily eat materials thinly coated with such an excessively bitter substance as strychnine, and again devour such a pleasant-tasting food as sugar cane, turning again with relish to such materials as salty bacon, sour apples, raw potatoes, or even chewing tobacco, which we have tested, why concern ourselves too much with flavorings in poison baits? It is the food requirement which largely governs food eaten by rats, when available. A wide series of experiments covering two and one-half years of indoor as well as field tests strongly indicate that flavorings to poison baits are much overrated, except perhaps when used against pampered city rats. This acute selective sense of smell and taste, then, would not seem to be readily utilized by rats in enabling them completely to avoid poison baits.

The highly developed sense of smell would seem to fit rats well in their location of food. We have no proof in the cane fields, however, that the handling of traps and baits contaminates them sufficiently to cause rats to avoid them. Unpoisoned baits, of various forms, used over a long period, daily handled by hand, are always readily taken by rats in the field. The same applies to our most successful poison baits.

From these facts it is no wonder that such prolific little animals, endowed with a capacity to enjoy and utilize as food anything from vermin and grass to the richest of human foods of every conceivable variety, and furnished with ample transportation facilities, whose natural enemies have been greatly reduced and excluded from many of their haunts, have become pests of major importance and cover the world over.

## Nesting Habits

Were it not for the very secretive nesting habits of the field rat, its control would not be so difficult. The gray rat makes its home in the ground, burrowing in generally for several feet, the depth of the burrow usually varying according to the depth and hardness of the subsoil. The sides of permanent ditches, cuts, cliffs, banks, and the sides of ratoon cane stools are much favored. Usually at the bottom of the burrow, about 1 to 3 feet in depth, a somewhat spherical, compact hollow nest is made, composed mostly of dry cane leaves and varying in diameter from 6 to 7½ inches. Dry grass is sometimes woven in with the cane leaves. The galleries of the burrow are often numerous; there may be several exits and one or two blind channels reaching toward the ground surface. The complete ramifications of the burrow may often extend for 5 or 6 feet and include two cane stools. Occupied burrows usually show considerable fresh earth piled outside of one entrance. The entrances to a burrow are frequently much con-

cealed in grass and trash. Investigators of rats in Java, where much careful work has been done, describe burrows and nests quite similar to those made by our field rat. A recent work by J. C. Van Der Meer Mohr on the biology of the Javanese field rat (1924) illustrates some burrows which could be closely ascribed to the gray rat.

Owing to the great concealment of these burrows in cane trash and grass, it is highly impractical to gas the burrows in cane fields, as it is done in banks along flooded rice fields in Java, where the nests are concentrated and more readily found.

The house mouse nests in the cane fields in much the same manner as the field rat. Burrows are made in the earth quite similar to those described above, though naturally smaller. They usually extend downward for 1 to 2 feet, may run laterally from 2 to 3 feet, have one or two branching galleries, and always terminate near the bottom in a small, ovoid nest, composed usually of dry cane leaves, varying in diameter from 3 to 4½ inches. No such nests have been found above ground except when made in buildings.

The black rat preferably nests in buildings. None have been dug out in cane fields in Hawaii, though they must occur to some extent in cane fields, for this rat is often trapped far from habitations. The related tree rat nests largely in trees, so far as our investigations show. The large nests are commonly found in Hawaii in thickets of pandanus trees well above ground. This is composed of dense clusters of the dry pandanus leaves placed in the mass of leaves terminating the limbs, as shown in Fig. 3, in the center of which an ovoid, ball-like nest is formed, comparable in size to that of the field rat. Similar nests are said to be made by this rat in algaroba trees and in the tops of coconut palms.

Fig. 3. Limb of Pandanus tree showing typical cluster of leaves at end which is frequently occupied by nests of the tree or roof rat.

The Javanese field rat is said to make definite runs or trails from its nest to feeding places. This is occasionally detected in Hawaiian cane fields, particularly where the burrows occur in grassy lands adjacent to standing cane. In the cane fields themselves these runs are not so readily detected, but upon close scrutiny can sometimes be found. We have found no advantage in searching for these in the application of poison.

Figs. 4 and 5. Showing Field 36, Honokaa Sugar Company, just after harvest to illustrate irregularity of the field and the extent of adjacent and included waste areas suitable for the establishment of permanent rat colonies. This field is chronically infested with rats.

The gray rat is said to drink much water. We have no striking evidence of their particular need for much water in the cane fields. The largest colonies are frequently found nesting far from any permanent streams or irrigation ditches.

Figs. 4 to 12 inclusive, taken at Honokaa Sugar Company and Pacific Sugar Mill, are given to illustrate the topography of land and the conditions of certain fields which are much favored by rats for nesting places. Such regions are chronically infested with rats.

Deep hollows, fields greatly broken with uncultivated waste arears, large rock piles, as shown in Figs. 13 and 14, numerous unplanted but overgrown gulches and large permanent ditches, furnishing constant vegetative cover, are favored by rats for the establishment of large undisturbed colonies. Such nesting places on cane plantations greatly assist in the development of a large rodent population, if climatic conditions favor them also.

Fig. 6. Another view of part of Field 36, Honokaa Sugar Company, showing intermixture of trees and shrubs, establishing permanent cover for rats within the field.

We have seen no indication of general migrations of rats in Hawaii. The appearance of large numbers in cane fields is the simple enlargement of colonies in favored feeding places.

Colonies of rats must move or migrate easily, however, from field to field in cane plantations. Freshly cut fields, well stocked with rats, having their burrows within these fields, leave them almost overnight following harvesting and settle in adjacent large cane or overgrown waste land. Many fresh burrows have been dug up in fields shortly after the cane was cut, but found already empty. It is the common experience on plantations to find many rats gathered beneath piles of cane in fields just cut. They have left the burrows, no doubt permanently, and have temporarily hidden beneath this freshly cut cane, for purposes of shelter

Figs. 7 and 8. Fields of Pacific Sugar Mill, showing the great irregularity of the country and extent of waste area occupying parts of every cane field. This section of the plantation (Kapulena) has always been notoriously infested with rats in the cane fields.

Figs. 9 and 10. Further views of Kapulena section, Pacific Sugar Mill, showing conditions favorable for the maintenance of permanent rat colonies.

Figs. 11 and 12. Field 30, Honokaa Sugar Company, just after harvest, showing favorable conditions for rat development.

Figs. 13 and 14. Parts of Field 30, Honokaa Sugar Company, just harvested, showing rock piles furnishing harbor for rats in such fields.

and food. Harvested fields are then not occupied again until the new crop is well up and supplying food and shelter.

## Rat Abundance

We would expect a certain relation between the rainfall in any community and rat abundance, the logical theory being that frequent heavy rains over many months of each year would prevent safe housing of litters of young rats in their nests in the ground, and that irrigated plantations would have few rats because of the frequent drowning of the young. Excessive rain no doubt does drown out a good many rats, but in the light of the data given in Table 2, we cannot accept the general theory. It is more reasonable to ascribe differences in rat abundance to differences in the quantity of available proteid foods and undisturbed nesting places on different cane plantations. The less gulches, rock piles, permanent waste areas and grass, weeds, shrubs, cover crops, etc., the smaller the rodent population should be. Irrigated plantations naturally have less rainfall than those unirrigated, and hence better grass and weed control, particularly away from the cane, and thus less available proteid food. We believe, in general, that insect food would be less abundant also.

Plantations in wet areas unavoidably have more grass and weeds constantly to contend with, both in and out of the cane. The seed of these plants furnishes proteid food for rats. Honokaa plantation has sufficient rainfall to have its grass and weed problem during average years, and in addition has an excess of suitable housing grounds for rats, which remain undisturbed in waste land, gulches, etc. This combination is unusually favorable at this place for rats. Here they have been exceptionally troublesome. Paauhau plantation, immediately adjoining, though under almost identical rainfall conditions, has, in general, considerably less rat damage. Conditions here are much less favorable for rats because of smoother fields, less waste land and hence less weed and grass seed supplying the necessary proteid foods and happy housing conditions.

The data of Table 2, covering a five-year period, showing rat abundance on five plantations on the island of Hawaii, having great differences in average rainfall, offer interesting food for thought. It seems to show that rainfall, in itself, is not an important factor in regulating the extent of rat populations. Thus Paauhau Sugar Plantation Company, with an annual average precipitation for the five-year period 1919-1923, of 59.52 inches, caught over the same period an average of 1.7 rats per trap per month, while Honokaa Sugar Company, adjacent to Paauhau, with nearly the same annual average rainfall for this period (64.19 inches), caught an average of 4.3 rats per trap per month, even though poisoning heavily the last one and one-half years, and for the first three years of the period, before poisoning commenced, caught an average of five rats per trap per month, or three times as many as at Paauhau. Differences in efficiency of poison gangs, if any, would not be sufficient to account for this. There is no questioning the

TABLE 2

**SHOWING AVERAGE NUMBER OF RODENTS CAUGHT PER TRAP PER MONTH AND RAINFALL ON 5 PLANTATIONS ON HAWAII FOR YEARS 1919-23 INCLUS**

| | 1919 | | | | 1920 | | | | 1921 | | | | 1922 | | | | 1923 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plantation | Avge. No. traps per day ........ | Total Rodents caught ......... | Avge. per trap per month ...... | Average Rainfall | Avge. No. traps per day ........ | Total Rodents caught ......... | Avge. per trap per month ...... | Average Rainfall | Avge. No. traps per day ........ | Total Rodents caught ......... | Avge. per trap per month ...... | Average Rainfall | Avge. No. traps per day ........ | Total Rodents caught ......... | Avge. per trap per month ...... | Average Rainfall | Avge. No. traps per day ........ | Total Rodents caught ......... | Avge. per trap per month ...... |
| **Olaa Sugar Company......** | 231 | 12,702 | 4.5 | 76.74 | 296 | 6,172 | 1.7 | 100.7 | 317 | 8,382 | 2.2 | 125.36 | 480 | 9,140 | 1.5 | 167.91 | 609 | 23,394 | 3.2 |
| Average for 5 years....... | 386.6 | 11,958 | 2.6 | 134.10 | | | | | | | | | | | | | | | |
| **Hilo Sugar Company ......** | 177 | 4,680 | 2.2 | 98.20 | 193 | 3,995 | 1.7 | 118.02 | 176 | 3,612 | 1.7 | 158.49 | 186 | 4,932 | 2.2 | 189.39 | 213 | 4,372 | 1.7 |
| Average for 5 years....... | 189 | 4,318 | 1.9 | 154.30 | | | | | | | | | | | | | | | |
| **Hakalau Plantation Co. ....** | 568 | 6,439 | .9 | 83.36 | 400 | 6,326 | 1.3 | 109.59 | 393 | 5,619 | 1.1 | 140.83 | 229 | 6,626 | 2.4 | 171.95 | 191 | 5,978 | 2.6 |
| Average for 5 years....... | 356.2 | 6,197 | 1.6 | 145.67 | | | | | | | | | | | | | | | |
| **Paauhau Sugar Plant. Co...** | 644 | 10,061 | 1.3 | 31.41 | 457 | 12,748 | 2.3 | 39.05 | 807 | 13,753 | 1.4 | 78.49 | 848 | 13,816 | 1.3 | 57.23 | 645 | 16,814 | 2.1 |
| Average for 5 years....... | 680 | 13,438 | 1.7 | 59.52 | | | | | | | | | | | | | | | |
| **Honokaa Sugar Company ..** | 508 | 36,039 | 5.9 | 40.53 | 485 | 34,673 | 5.9 | 40.71 | 554 | 29,536 | 4.3 | 89.52 | 272 | 10,518 | 3.2 | 58.46 | 582 | 14,909 | 2.2 |
| Average for 5 years....... | 480 | 25,135 | 4.3 | 64.19 | | | | | | | | | | | | | | | |

belief that rats have been much worse at Honokaa than at Paauhau. Again, Paauhau Sugar Plantation Company, with less than half as much rain as at Hakalau Plantation Company or Hilo Sugar Company, caught nearly the same quantity of rats per trap per month as at these places, and considerably less than the number caught at Olaa plantation, where the rainfall is also more than double that of Paauhau. These facts all tend to show that rainfall is not the controlling factor in rat abundance, but that plenty of cover with grass and weeds is.

**TABLE 3**

**NUMBER OF RODENTS CAUGHT ON ISLAND OF HAWAII FROM JULY 1, 1914, TO JUNE 30, 1922**

| | 1914-15 | 1915-16 | 1916-17 | 1917-18 | 1918-19 | 1919-20 | 1920-21 | 1921-22 |
|---|---|---|---|---|---|---|---|---|
| Olaa Sugar Co., Ltd. | 6,330 | 6,813 | 7,504 | 7,389 | 6,824 | 7,006 | 7,580 | 12,528 |
| Waiakea Mill Co. | 3,462 | 5,148 | 4,492 | 4,182 | 4,307 | 4,542 | 2,568 | 649 |
| Hawaii Mill Co. | 603 | 38 | 235 | | | | | |
| Hilo Sugar Co. | 4,251 | 4,901 | 4,972 | 4,120 | 4,160 | 4,523 | 3,520 | 3,509 |
| Onomea Sugar Co | 5,740 | 5,894 | 5,975 | 6,171 | 6,611 | 6,999 | 7,587 | 9,337 |
| Pepeekeo Sugar Co. | 4,996 | 4,331 | 3,329 | 2,736 | 2,724 | 3,539 | 3,843 | 4,217 |
| Honomu Sugar Co. | 5,031 | 5,020 | 4,714 | 3,686 | 3,844 | 3,157 | 2,297 | 2,379 |
| Hakalau Plantation Co. | 4,755 | 7,736 | 6,617 | 5,753 | 7,276 | 5,768 | 4,171 | 3,731 |
| Laupahoehoe Sugar Co. | 9,037 | 9,245 | 5,716 | 8,378 | 10 914 | 16,434 | 7,960 | 8,081 |
| Kaiwiki Sugar Co., Ltd. | 10,618 | 14,224 | 10,847 | 11,168 | 15,753 | 19,219 | 21,623 | 19,471 |
| Kukaiau Sugar Co. | 3,822 | 7,241 | 7,623 | 5,883 | 6.035 | 8,328 | 576 | 5,646 |
| Hamakua Mill Co. | 8,044 | 11,775 | 13,486 | 10,867 | 10,592 | 9,421 | 9,018 | 11,968 |
| Paauhau Sugar Plant. Co. | 10,065 | 9,565 | 8,342 | 9,001 | 10,375 | 11,122 | 10,893 | 13,964 |
| Honokaa Sugar Co. | 23,163 | 23,828 | 28,007 | 28,977 | 34,842 | 37,864 | 20,317 | 19,448 |
| Pacific Sugar Mill | 14,718 | 14,696 | 15,748 | 12,545 | 18,325 | 15.266 | 9,076 | 9,447 |
| Hilo City | 5,933 | 6,351 | 8,104 | 9,605 | 9,400 | 7,836 | 5,385 | 6,946 |
| Laupahoehoe Village | | | | | 3.319 | 298 | 949 | 3,336 |
| Paauilo Village | | | 1,911 | | | | 671 | 903 |
| Kukaiau Village | | | 844 | | | | | 1,876 |
| Honokaa Village | 1,448 | 1,162 | 767 | 256 | 157 | 405 | 808 | 2,952 |
| Kukuihaele Village | 2,853 | 2,761 | 1,570 | 1,440 | 788 | 708 | 1,544 | |
| Waipio Valley | 2,748 | | | | | | | |
| TOTAL | 127,617 | 140.729 | 140,803 | 132,157 | 156,246 | 162,435 | 127,627 | 140,388 |

Table 3 is given to show the abundance of rats on the island of Hawaii. These data were kindly furnished by the Territorial Board of Health. Thus, with from 200 to 600 traps set daily in twenty-two localities, over a distance of about sixty miles, operating mostly from 1914 to 1922 inclusive, a total of 1,128,002 rodents were caught, averaging about 141,000 a year. This trapping under the supervision of the Board of Health, for plague control purposes, continues.

Table 4 illustrates the large rodent population present at Honokaa. The number of rats caught per trap per month is much in excess of that of any other plantation on Hawaii, and has remained consistently so, year by year, until 1922, when control measures were adopted, as discussed later.

A close estimate of the actual extent of a rodent population in any community or section of it is very difficult to make. We can base our conclusions mostly from the number caught by trapping over a short period. The catch at Honokaa Sugar Company between 1915 and 1921, inclusive, ranged from 22,894 to 36,039 per year. From 481 to 554 traps were used daily during the entire period. As there are about 5,000 acres under cane on this plantation, half of which is generally under cane large enough to support rat colonies, 500 traps can only very partially cover the ground occupied by rats. One concentrated effort, however, in a 105-acre field of cane at Honokaa Sugar Company, in April, May and June, 1923, has thrown some light on the extent of the rodent population in cane fields where conditions favor them. This field was under harvest when the trapping began. It showed a rat damage to 11.7 per cent of the stalks, as indicated by an examination of 22,600 sticks. This was after heavy checking of the rats by poisoning for nearly a year, and represents an average damage somewhat less than that in most fields favored by rats at Honokaa prior to the inauguration of a poison campaign. A total of 1,000 traps, placed in parts of this field and daily operated during April, May and June, caught 3,127 rats and 834 mice. At the close of the period about a dozen rats were being caught daily in the thousand traps. The field was also heavily poisoned during the trapping period, hence the actual number of rodents present must have been considerably in excess of 3,961. This represents a minimum of about thirty-seven per acre, without including many killed by poison. We can reasonably assume the population of this field to have been twice the number trapped prior to harvesting the cane. Assuming a conservative average of seventy rats per acre in well advanced cane, based on the trapping results in this particular field, the number of rats present at any one time in 1,000 acres of fields favorable to rats on this plantation, would be 70,000. Before poisoning began at Honokaa, no field man familiar with conditions there would consider this an overestimate.

## Extent of Damage

The annual loss in foodstuffs caused by rats and mice, over the entire civilized world, must be very great. No estimate can ever be very accurately drawn. Many have been made and some are very interesting. It is generally assumed that most computations of this nature are exaggerated, even when prepared by competent authorities. Such estimates, however, tend to be made from the losses in large storage centers, warehouses, large farms, plantations, etc., without including the sum total of the small losses in nearly every household.

Estimates in Porto Rico give the annual loss at $75,000. David E. Lantz ventured the opinion in 1917 that the number of rodents in the United States was two or three times that of its human population. Assuming a two-dollar annual loss caused by each rat, he estimated the annual loss at $200,000,000. Authoritative estimates in Europe have placed the damage in Great Britain at $73,000,000,

in France at $38,500,000, Germany $47,640,000, and Denmark at $3,000,000. Lantz computed the annual loss in the city of Washington, D. C., and placed it at $400,000, and $700,000 for the city of Baltimore.

Major Kunhardt, member of the Plague Research Commission in India, states in the *Indian Journal of Medical Research,* 1919, that during the preceding twenty years, the total loss in India due to rats, including plague losses, amounted to over four billion dollars.

Much careful and accurate data have been secured on losses from rat ravages in Hawaiian cane fields.

In 1920, G. H. Haldeen, then Chemist of Honokaa Sugar Company, made a series of comparative analyses of rat-injured and sound cane. His figures in conclusion showed a quality ratio of 7.57 for sound cane and 14.02 for average rat-injured cane. These computations indicated that it took nearly twice as many tons of rat-injured cane to produce a ton of sugar as sound cane, owing to juice deterioration. This was prior to poison control at Honokaa, and from 25 per cent to 40 per cent of the canes were said to have been rat damaged.

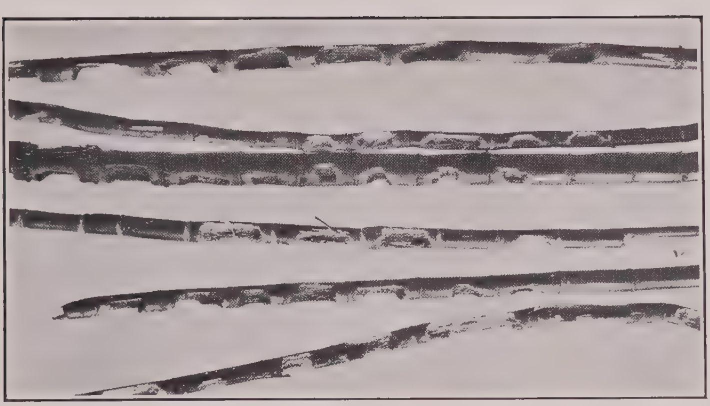
In 1922, P. H. Bartels, Assistant Manager of Honokaa Sugar Company, compiled an estimate of sugar losses from rat damage at Honokaa Sugar Company and Pacific Sugar Mill. This careful estimate, based on comparative analyses of rat-injured and non-rat-injured cane, together with losses from dead cane left in the field, which had been killed outright by rats, elucidated surprising information. Basing his conclusions on an average market price of sugar of $110 per ton, the very interesting fact is brought out that the two plantations, harvesting a total of 13,522 tons of sugar in 1922, lost 19.17 per cent of the crop from rat injury, or 2,592 tons of sugar. At $80 per net ton, this loss amounted to $207,360. A loss of $207,360, or 19.17 per cent of the potential crop, is vastly more than one would expect had no such analysis been made.

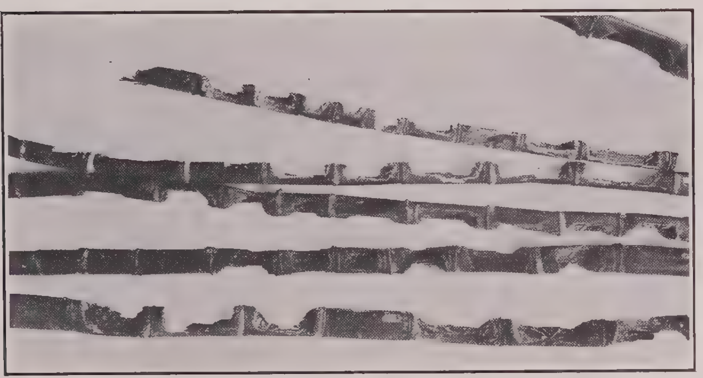
In the light of further studies, the above computation is amply confirmed. The sugar loss lies not only in the particular joints of the stick attacked, for fermentation or general deterioration of the whole stick occurs above and below the injured joints, the juice deterioration being greater the nearer to the eaten part of the stick it lies. During August and September, 1923, eighteen separate lots of rat-injured and sound canes were analyzed by A. Fries, Chemist of Honokaa Sugar Company. In each case entire sticks were cut and the total extracted juice was used for comparative tests. The selected rat-injured cane was not badly injured, there being only from one to three injured joints per stick. The sound canes were selected from the same stools as the injured ones, and an attempt was made to have each of the same age and height for each separate lot. The results are very interesting, for they show how large a loss in sugar may occur even in canes slightly rat damaged. The average from the eighteen lots showed a requirement of 10.41 tons of cane for a ton of sugar in the rat-injured lots, and 8.77 tons of cane for a ton of sugar in the sound lots. This is an actual sugar loss of 14.9 per cent in canes only mildly rat damaged. When 25 per cent of the canes over the entire plantation are rat injured, a 14.9 per cent loss in sugar in one-quarter of the cane produced amounts to the difference between success and failure on such places as Honokaa Sugar Company and Pacific Sugar Mill, excepting when sugar prices are above normal.

During 1923, Raymond Elliott, Chemist of Paauhau Sugar Plantation Company, made a careful study of the sugar loss in rat-injured cane in five fields, covering twenty-six separate experiments. For the five fields he found an average of 32.12 per cent of the stalks rat eaten. This degree of injury, he found by analysis, caused a loss of 5.86 per cent of the sugar per acre, or, from these particular fields, a loss of $51.88 per acre, with sugar at 7 cents per pound. These data neither include losses from cane killed outright in the field and left dead and scattered away from the stools where they originally grew, nor do they, or the preceding estimates, include the general injurious effect upon the stool itself caused by heavy fermentation and rotting of standing injured cane.

Rats generally attack the cane stalk and not the leaves. Most of such injury commences after considerable stick has formed and some sugar is present. Very young cane, less than six months old, is usually not favored, though occasionally it is found damaged. Canes then eaten are often killed outright. All parts of the stick in mature cane may be eaten, but most of the damage occurs on the lower, protected half. This does not apply to cane which has fallen over. A great deal of the chewed tissue is not swallowed. Piles of finely chewed cane tissue are always found beneath and about injured cane. Rats probably endeavor, as a rule, to obtain the juice only, but their excrement in cane fields is composed mostly of cane fiber. Often eight or ten successive joints of a stick are almost completely eaten out, and sometimes a joint is eaten clear through and

Fig. 15. A spot in a field of D 1135 cane freshly attacked by rats, showing broken-down effect.





Figs. 16, 17 and 18. Showing typical appearance of cane when badly attacked by rats.

the stick beyond this joint is a total loss. The cane continues growing, usually, if only a small bit of the rind remains to connect the stick with the basal portion or stool. Fields badly attacked often become much fallen over from the immediate effects of the attack and from breaking down through wind pressure on weakened stalks. Fig. 15 shows a spot of vigorous cane considerably disrupted by rats. Sometimes parts of fields are so badly injured as to be unfit for harvesting.

Figs. 19 and 20. Views of Field 9, Pacific Sugar Mill, following harvesting the crop of 1923 and showing dead cane left in field, mostly due to original rat damage.

Fig. 21. Field 19, Honokaa Sugar Company, after harvest, showing dead cane lying in field, resulting mostly from rat damage. Crop of 1923.

Figs. 16, 17 and 18 show the typical appearance of cane eaten by rats.

The data covering the actual degree of damage to cane at Honokaa Sugar Company and Pacific Sugar Mill, where rats seem to be more prolific and numerous than in any other cane region in Hawaii, are not large. It was not until a serious effort was made to determine the sugar loss in injured canes, and rat control methods were developed, that attention was greatly given to the extent of field damage. Honokaa Sugar Company obtained a count of the damaged canes in their fields of the 1922 crop. As this had been partially poisoned in an experimental way, the figures do not give an accurate record of average losses during preceding years, but the record is of value, for it gives us a basis for comparison with present conditions following the development of control methods. This count covered eleven fields. A total of 24,100 canes were examined. An average of 18.9 per cent were damaged by rats.

During 1922, the writer had opportunity to make estimates of the amount of dead canes left lying in certain fields after the living cane had been harvested. These examinations were made in fields badly rat injured. It is assumed that most, but not all, of the dead cane so measured had been killed by rats. Figs. 19, 20 and 21 show the appearance of parts of these fields after the cane had been harvested. Fields usually showing from 5 to 8 per cent of the sticks rat damaged have no noticeable dead cane left on the ground after harvesting. When the damage reaches 15 to 20 per cent it is quite discernible, and where damage amounts to 30 per cent, 40 per cent, or over, it is particularly conspicuous. Following the harvesting of Field 9, Pacific Sugar Mill, on September 29, 1922, which showed heavy rat damage, a measurement was made of dead cane in a definite area in the field. Assuming a linear foot of average cane to weigh one-half pound, this computation showed 11.3 tons of dead cane per acre left on the

field. A similar examination was made in August, 1922, in Field 28, Honokaa Sugar Company, in a portion which had been badly attacked by rats. The computation gave 38 tons of dead cane per acre present on the ground.

### Control

Intensive warfare on rats has been under way in many parts of the world for a long time, but it is generally sporadic and discontinuous. It can hardly be said that, in general, any very satisfactory control has ever been achieved which has remained permanent for very long. Rats seem to go on increasing with the increase in human population and the consequent increase in the production of food. The only manner by which rats seem to be most successfully checked, in large population centers, is through the modernization of structures, buildings, streets, sewers, etc., whereby suitable cover or hiding places for rats are eliminated and food storage structures made ratproof. This improvement in building and sanitation may in time greatly reduce rodents in cities, but elsewhere the oft-repeated recommendation of "building the rat out of existence" can hardly apply.

The use of traps, poisons, dogs, cats, ferrets and diseases is not new in rodent control. The protection of natural enemies such as owls, weasels, snakes, etc., is of value on farms, but of no great use in cities where conditions of life do not favor them. Every community having its rodent problem in the modern world, has given attention to various methods of artificial control with more or less periodic success, but from the constantly increasing bulk of literature on the subject, appearing wherever rats have been serious pests, we learn that they are still pests and the success in control has been but short lived. We have read much of rat drives, rat weeks, annual community campaigns, etc., wherein great quantities of rats, often many thousands at a time have been killed, indicating a temporary success; but such enthusiasm soon dies out and the prolific rodents shortly assume their normal balance again in relation to the available food. Such campaigns can only be of short duration, for the average individual is vitally concerned in matters other than killing rats, and the warfare continues only on a small scale by a limited group, whose employment is solely for rat extermination, supported by boards of health and public organizations with funds far from commensurate with the importance or needs of the problem. Their efforts can by no means gain headway over the normal rate of rodent increase.

### Traps

Trapping is usually a favorite method of destroying rats. Barrel, snap, and cage traps are common forms. Trapping has, perhaps, always been popular and preferred to poisoning, because of psychological reasons and from a practical standpoint. We assume, from the layman's point of view that a dead rat in a trap is worth two in the bush. The poisoned rat is seldom seen, but the trapped one is. Trapping, to be successful, is an expensive operation, excepting where it is desired to catch a few rats in a house or small area not chronically inhabited by large numbers of rats.

On cane plantations or in large agricultural regions where rats are numerous, trapping can only be successful and keep pace with rodent increase when con-

ducted on an exceedingly large scale. A 5,000-acre cane region under conditions such as at Honokaa Sugar Company, can do little with 1,000 traps operated daily, excepting to quickly check heavy damage in a particular spot. One thousand traps spread over 500 acres can, at the most, catch two rats per day per acre, if set once a day. The normal increase per acre would easily exceed this. Honokaa Sugar Company and Pacific Sugar Mill caught with traps during the six years 1915 to 1920 inclusive, a total of 268,761 rodents at a cost of about $10,000 a year. No visible results could be seen so far as checking the amount of damage to the cane went, and more rodents were caught the last year per trap than the first year, as shown in Table 4. Perhaps results of value could have been obtained if ten times that number of traps had been used daily, but the expense would be prohibitive, compared with poison costs and results, as discussed later. We do not, then, favor trapping in large rat campaigns on cane plantations as a major operation. They are only useful in a minor way.

Of the traps generally used, the steel, spring or snap trap is the most serviceable and efficient. Bacon has been a satisfactory bait at Honokaa. Toasted coconut has been used with success at Grove Farm Company, Ltd., on Kauai.

Investigators in Java have reported fair results in digging out rats from their burrows as well as trapping them. This applies particularly to rice fields, where rat burrows become concentrated in the dikes or banks separating sections of flooded fields and are hence more easily found than in cane fields. They have also had a certain degree of success in gassing such burrows with carbon bisulphide.

## Virus

There is voluminous literature on the use of bacterial viruses in the control of rats. The host of parasites and diseases which rats are known to harbor is strongly indicative of their high resistance to any such means of repression. The deadly bacillus of bubonic plague, though often fatal to rats, would not seem to be a controlling factor. In the Hamakua district of Hawaii, where plague has been present for nearly fiteen years, rats are more numerous and destructive than in any other part of Hawaii where plague does not occur. We cannot reasonably expect any milder bacterial disease to control rodents when plague does not do so.

F. Loeffler isolated a bacillus in 1889 which was pathogenic to mice. This was described as *Bacillus typhi murium*. J. Danysz later corroborated Loeffler's work and in 1900 isolated a bacillus, resembling that of Loeffler, which was often fatal to mice and to some rats. In June, 1893, S. S. Mereschkowsky found an organism of similar nature to that of Danysz and Loeffler in ground-squirrels.

Since the original work by these men and by several others, many commercial preparations have been on the market, known as rat viruses. Testimonials highly recommending them have been frequent, and accounts of results have read well, but careful and continued investigations have usually shown them to be of little value. We have tested commercial preparations of this type without success. We have secured direct from the Agricultural Experiment Station at Sugamo, Tokyo, Japan, December 8, 1922, fresh cultures of the bacilli of Loeffler, Danysz and Mereshkowsky, where such viruses have

been reported as successfully used against rats and mice, but all attempts with them failed here. Rodents which were fed the fresh material from the cultures, as well as the commercial preparations, were tested carefully and held for longer periods than required for the development of the disease, yet at no time did they exhibit any signs of discomfort. Mice were used as well as rats, with negative results. If these preparations had lost their virulence by the time of use, this tendency alone would argue against their adoption, even when fresh. In large scale operations, involving considerable expense, any risk of failure in virulence in a virus cannot be taken. We consider it safer to apply poisons, the effects of which are definite and consistently so.

## Poisons

Poisons have been used with more or less success in rodent control in Australia, England, South Africa and the United States. Many proprietary mixtures have long been on the market, having mostly as their toxic element strychnine, barium carbonate, phosphorus, arsenic and extract of squills. One of the most complete compilations of commonly used rat poisons, is a paper by Wm. F. Schlupp, entitled *The Destruction of Rodents by the Use of Poisons.* published by the Department of Agriculture, Union of South Africa, as Bulletin No. 4, 1921. This gives the composition of thirty proprietary mixtures and about twenty other useful formulae. Most of these have a certain merit and many are of high value.

In our study of rat control in Hawaii, practically all of the mixtures mentioned by Mr. Schlupp have been tested. In the light of final results, it would appear that rat control by poisoning has not been greatly successful in most countries, not because of the ineffectiveness of most of the baits used, but from the sporadic nature of the campaigns, the discouragement resulting from hastily drawn conclusions, based on first appearance and small rodent outbreaks and from the general failure to "carry on" on a large scale continuously.

## Poison Work in Hawaii

*Laboratory Tests*: Apart from large scale applications of barium carbonate and strychnine at Honokaa Sugar Company and Pacific Sugar Mill, over a period of two and one-half years, many separate field tests have been made and a total of 428 separate laboratory tests have been completed in an investigation of the value of barium carbonate and strychnine in various bait forms. Arsenic, extract of squills, phosphorus and cyanide of potassium were also tried in combination with several foods and flavorings.

Owing to the presence of bubonic plague in the district, most of the indoor experiments were conducted in galvanized iron cans instead of wooden boxes or screened cages, thus preventing infected fleas from escaping from the confined rats. Two plague rats died in these cans during the period of experiment, and the plague bacillus was demonstrated to be present in the body of fleas taken from one of the rats. Though these cages necessarily confined the rats in an unsatisfactory environment, preventing proper exercise, they proved satisfactory in testing the killing properties of poison bait. The extent to which such baits would be normally eaten was determined in the field.

All poison baits experimented with were made up of materials which would prove sufficiently cheap to manufacture in large bulk, if satisfactory. Expensive or highly perishable substances such as fresh fruits, vegetables, meats, cheese, etc., were necessarily excluded in most of the tests.

The laboratory tests with strychnine and barium carbonate are briefly summarized. The exact formulae for the most useful baits are given later. The laboratory results were as follows:

In experiments with barium carbonate mixed dry with rolled oats, wheat flakes or dry flour in a ratio of 1 part barium carbonate to 3 to 6 parts oats, wheat or flour, 113 tests with rats and 29 with mice proved fatal in from a few hours to 6 days, in which about 1.5 to 2 grains of pure barium carbonate was consumed from the mixtures. Three cases occurred in which rats refused to eat it, or barely tasted the bait, after 16 to 28 days' trial. Most fatalities occurred within 3 days after the poison was eaten.

A dry mixture of whole wheat and barium carbonate at a proportion of 1 part barium carbonate to 4 parts wheat proved fatal in each case in 41 tests on rats and 4 on mice, a very small amount of wheat being taken in each case.

Barium carbonate cake mixtures composed of 1 part barium carbonate to 3 parts wheat flour mixed into dough, cut into cakes, dried out and hardened, proved fatal in each of 32 tests on rats and 48 on mice, the quantity of cake eaten in each case generally varying in amount from less than 1 grain to about 3 grains. Death usually occurred in 1 to 3 days but in some cases not until 8 or 9 days.

Strychnine (alkaloid) applied in thin paste media to whole wheat in a proportion of 1 ounce strychnine to 20 or 25 pounds of grain and then dried, was tested 53 times on rats and 36 on mice with success, rats usually consuming from ¼ to ½ ounce of the bait, and mice from 5 to 15 of the wheat grains before dying. Eight rats, in all, failed to die after a large consumption of this bait, the greatest quantity taken by one rat being 6 ounces in 15 days' time without apparent discomfort. It is usually fatal in a few hours to rats and often in a few minutes to mice.

In 15 separate tests of strychnine (alkaloid) mixed dry with rolled oats or wheat flakes at ratio of 1 ounce of strychnine to 20 or 25 pounds oats, or wheat flakes, it proved fatal to rats in each case.

In 39 tests on rats and 3 on mice, using pure barium carbonate spread thinly over the surface of freshly cut slices of sugar cane, each proved fatal in from a few hours to two days. Four similar tests were successful on rats, using a fraction of a grain of strychnine (alkaloid) sprinkled on the surface of thinly cut slices of sugar cane.

Six tests on rats were made with phosphorus mixed into flour dough and dried. The rats in each case ate a small bit of the cake and died within two days, but field experiment with this material indicated a too rapid deterioration.

Several tests with potassium cyanide, dissolved in water at a ratio of 1 ounce to 6 gallons of water, proved fatal to rats and mice in less than one day, but for various reasons it was not considered a valuable bait for large field application.

Arsenic and extract of squills were tried in the laboratory but given up because less satisfactory than the strychnine and barium carbonate tests. Arsenic proved more toxic than squills.

In all of the laboratory tests fresh sugar cane was kept in the containers. This supplied water and a suitable natural food. Large rats were nearly always more difficult to poison than smaller ones. They not only showed keener perception of the dangerous nature of the baits but were distinctly more resistant to the poisons.

Such marked success appeared to follow the application of strychnine wheat and barium carbonate cakes at Honokaa Sugar Company, early in 1922, and these baits had so much in their favor because readily adaptable to large scale application in form reasonably imperishable and cheap that most of the experimental study has been with these poisons, with the aim of preparing a bait acceptable to rats, one which they would readily eat. The exact formulae of mixtures containing other poisons will not be given, since they were considered inferior to several barium carbonate and strychnine baits, as judged by experiment. Only baits which appeared to have definite merit are cited. Where thousands of acres are treated it would be superfluous to recommend or give serious consideration to fancy mixtures such as might be used in a household where protection from rain, etc., is complete and costs do not enter into the problem.

## Poison Formulae

The following formulae have been effective in the laboratory, some having been widely used at Honokaa Sugar Company and Pacific Sugar Mill and to some extent on other plantations in Hawaii and found satisfactory. All are cheap and easily prepared by any trustworthy and reasonably intelligent person. None are fatal to man, chickens or other animals, excepting rodents, unless taken in fairly large quantities. No such trouble has been experienced at Honokaa where tons of strychnine and barium carbonate baits are now annually used. They are all poisonous, however, but the very nature of the baits, as given, are hardly palatable to most animals excepting chickens and we have had no trouble even with them.

E. Boulenger conducted experiments at the Zoological Garden, London, and found that 10 to 15 grains of pure barium carbonate was harmless to a chicken, 100 grains to a dog, but 1½ to 2 grains killed a rat almost invariably. A 60-grain dose of barium carbonate has proven fatal to man. Small amounts of it, such as contaminates the hands, nose or mouth of workers in it, are not dangerous.

General consideration of each bait will be given and several discussed in detail elsewhere in this paper. Several have been used for many years in other parts of the world.

### Number 1

Barium carbonate cake, Rat X or Honokaa Cake:

Barium carbonate (by weight) 1 part.

Flour, or preferably middlings, 3 parts.

Mix the two together, add enough water to knead into a stiff dough, roll into sheets about ¼ inch thick, cut out small cakes about ½ inch in diameter and

dry thoroughly in an oven or by the sun. It is then ready for use. A small portion of 1 cake is usually fatal to any rat.

A method of rainproofing these cakes, conceived by W. P. Naquin, Manager of Honokaa Sugar Company, has been developed by himself and F. R. Giddings, by which the life of each cake has been considerably lengthened, after application in the field. By this method each cake, after being dried and hardened, is coated with a thin film of paraffin. This greatly retards mould development and general deterioration. Figs. 22, 23, 24, 25 and 26 illustrate this form of bait. Salt and other flavorings have been added occasionally, but field tests show no advantage in the use of flavorings. Perhaps a little salt improves a bait, though we are not certain of this.

Barium carbonate does not easily deteriorate. Cakes of this type, kept in dry storage for two years were tested on live rats and found to be as effective as fresh cakes. Any moulding whatever ruins the bait. It does not lessen the toxicity, but renders it unpalatable to rats and mice.

Pure barium carbonate has cost from $60 to $70 per net ton f. o. b. steamer, New York.

### Number 2

Barium carbonate flake:

This is a modification of Formula No. 1. The dough in this case is rolled out very thin, the thinner the better. It is best about the thickness of blottng paper. The sheets can then be sliced or cut into thin ribbons and small flakes about ¼ inch square cut therefrom. These are then dried until crisp. They form a very satisfactory bait if kept dry and replaced as soon as mould appears.

### Number 3

Barium carbonate oats:

| | |
|---|---|
| Rolled oats (dry) by weight | 6 parts |
| Barium carbonate | 1 part |

Mix the two ingredients thoroughly. It can be most satisfactorily done by placing the materials in a tight can and shaking vigorously. This bait has given good results. A modifictaion of this is to use rolled wheat, or wheat flakes (a common breakfast food), instead of the rolled oats. This is best applied in torpedo form, as shown in Fig. 28.

### Number 4

Barium carbonate wheat:

| | |
|---|---|
| Whole wheat (dry) by weight | 6 parts |
| Barium carbonate | 1 part |

Mix by shaking the two vigorously in a tight can.

### Number 5

Barium carbonate flour:

| | |
|---|---|
| Middlings or whole wheat flour (dry) by weight | 3 parts |
| Barium carbonate | 1 part |

Fig. 22. Coating barium carbonate cakes with paraffin at Honokaa Sugar Company. The cakes are dumped into the pan of melted liquid paraffin in front of the operator, then the tray in the pan is raised and the cakes are thrown to the slide at her left and fall through the air to the pan of water below, thus completely and evenly coating the cake with paraffin and hardening the coating in one operation.

Fig. 23. Freshly made barium carbonate rat poison cakes drying in the sunlight at Honokaa Sugar Company.

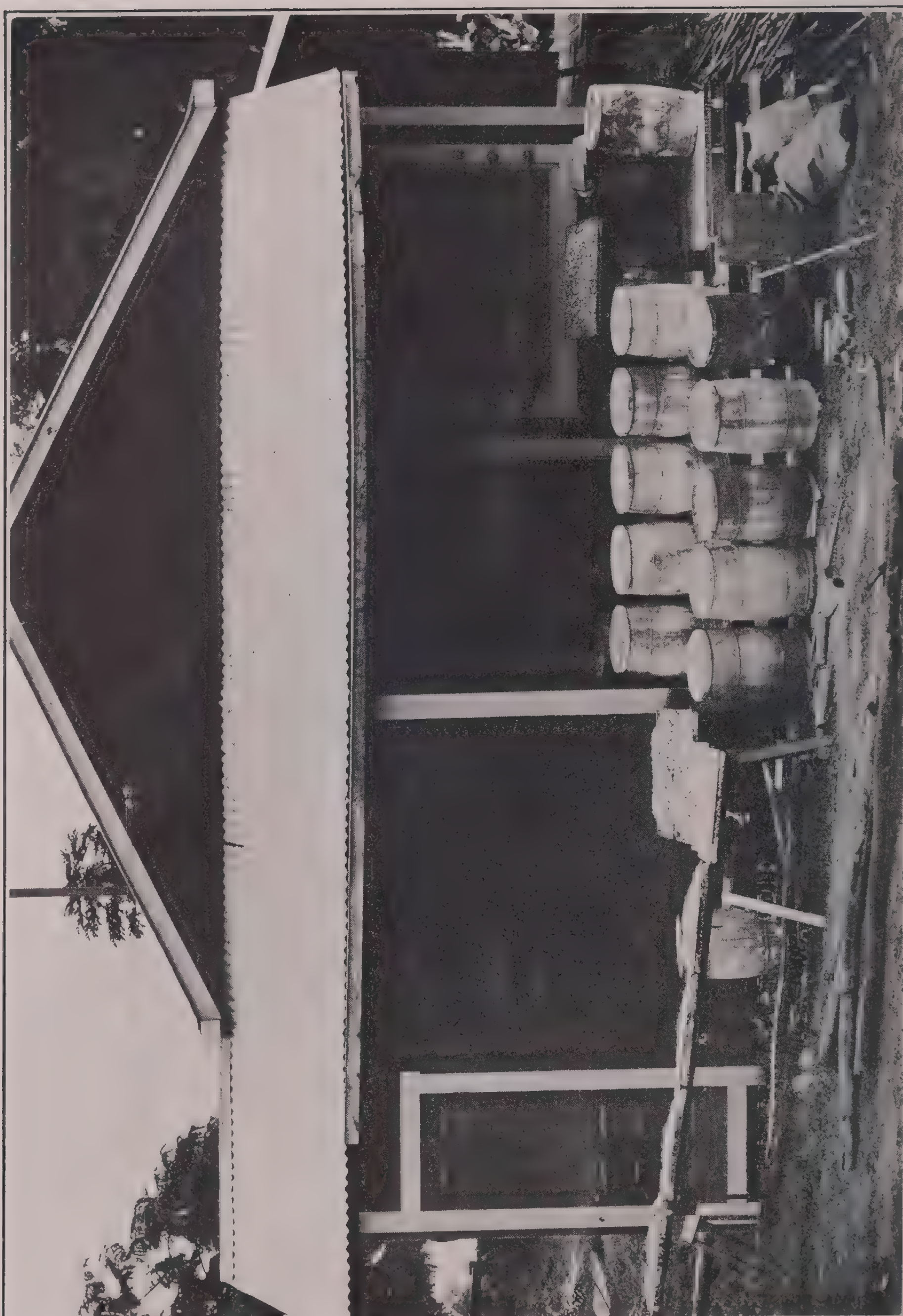


Fig. 24. Completed barium carbonate rat poison cakes in front of the poison house ready for storage. Honokaa Sugar Company.

Fig. 25 Completed barium carbonate rat poison cakes ready for use at Honokaa Sugar Company.

Fig. 26. Three tons of barium carbonate rat poison cakes in storage at Honokaa Sugar Company.

Fig. 27. Japanese women wrapping bamboo capsules filled with strychnine-wheat in paraffin paper. Honokaa Sugar Company.

Mix the two together thoroughly. This is Formula No. 1 without wetting it or mixing into a dough. It is applied by wrapping up into small paraffin paper packages or torpedoes, as shown in Figs. 27 and 28. It has given fair results, but does not seem so satisfactory as any of the preceding barium carbonate formulae.

NUMBER 6

Strychnine wheat:

| | | |
|---|---|---|
| Powdered strychnine (alkaloid) by weight | 1 | ounce |
| Baking soda | 1 | " |
| Salt | 1 | " |
| Saccharine | 1 | teaspoonful |
| Laundry starch | ½ | cupful |
| Whole wheat | 25 | pounds |

Fig. 28. The torpedo form of poison bait, wherein loose, dry poisons, such as rolled oats, wheat, wheat-flakes, etc., are wrapped in small squares of paraffined paper, usually one-half to one ounce per torpedo.

One good way of making this bait is to mix the soda, saccharine, salt, starch and strychnine in one quart of water, heat slowly and stir continuously until a fairly creamy paste is formed. This paste is then poured over the grain which is stirred and mixed until all the wheat is wet with the paste. This stirring is best done in a wooden tray, tub or box. The wheat is then thoroughly dried in trays and is ready for use. Methods of its application are discussed later.

There are several other methods of coating the wheat. One is to make the paste first, with all ingredients but the strychnine, and finally add the strychnine, while the paste is fairly thin and hot, stirring cotinuously.

This is a favorite rodent poison in many parts of the world.

Strychnine must be handled with some care. Tonic medical doses of strychnine are given to man in solution or in pill form, ranging from 1/60 to 1/15 of a grain. A half grain has proven fatal to man. Exceedingly small quantities are usually fatal to rats and mice.

Pure strychnine (alkaloid) has cost $1.11 per ounce.

The wheat bait, as described, has been sold commercially for about 16 to 18 cents per pound. It has been used at Kilauea Sugar Plantation Company, Koloa Sugar Company, Paauhau Sugar Plantation Company, Grove Farm Company, Ltd., McBryde Sugar Company, Ltd., Pepeekeo Sugar Company, Honokaa Sugar Company, and to some extent on some of the other plantations in Hawaii.

### Number 7

Strychnine oats:

| | |
|---|---|
| Strychnine (alkaloid) by weight | 1 ounce |
| Rolled oats or wheat flakes (dry) | 15 pounds |
| Baking soda | 1 ounce |

Mix the ingredients thoroughly by shaking well in a tightly closed tin or box.

### Field Poisoning at Honokaa Sugar Company

The very effective utilization of rat poisons at Honokaa Sugar Company has been almost entirely with Formulae Nos. 1 and 6. Early in 1922, large operations began with these baits. From the first proof that rats would eat them in the field, and that indoor tests showed that such feeding killed them, it was reasonably concluded that a continuous use of such baits in the field, covering the entire plantation, could be expected to bring favorable results. This policy of continued and wide application is the key to the ultimate success of the whole campaign.

A complete discussion of the exact methods used at Honokaa has appeared in several preliminary reports. It will be only briefly summarized here. As the campaign has been successful, a record of the exact procedure will be of interest.

The crop harvested in 1923 was the first to receive careful attention. Commencing in May, 1922, systematic poisoning began. Twenty-one fields were treated at Honokaa. Each field from May, 1922, until July, 1923, received from 3 to 5 complete treatments of poison. The fields were all treated twice in 1922 with Rat X cake (Formula No. 1), and once, in December, with strychnine wheat (Formula No. 6). Ten of the fields received two additional applications of Rat X cake in 1923, eight of them one additional application in 1923, and three other fields each received a treatment of strychnine wheat again in 1923. This cane covered 2,507 acres, the total cost of the poison manufacture coming to $3,506.71, and its application with some trapping $1,960.53, there being nearly 15,000 rodents caught. The total cost of the rat work at Honokaa was then $5,467.24 for this crop. In the annual report of the manager, for this crop the total number of poison baits applied is given as 5,000,000. This was not all put on the 2,507 acres of cane harvested, as much adjacent waste land was necessarily treated.

The original plan at this plantation of placing one bait on every 100 square feet of land, at each treatment, has been carried out as near as possible. Pacific Sugar Mill, under the same management, was similarly treated.

As an example of the intensiveness of the rat work at Honokaa, 2,333 acres of cane were treated three times in 1922, at a total cost of $1,125, which is roughly 7,000 acres treated once. Thus the manufacture and application of this cost about 16 cents per acre, which has now been somewhat reduced. During the month of August, 1922, 10,200 pounds of barium carbonate cakes were manufactured, totaling 2,703,000 cakes, at a cost of $208, exclusive of the cost of material. By September 1, 1922, 16 tons of cakes had been made, totaling 7,614,185. Figs. 24, 25 and 26 show some of this poison on hand just after manufacture.

The large application of strychnine wheat in December, 1922, also indicates how energetically the work was done. For the two places, Honokaa Sugar Company and Pacific Sugar Mill, 3,422 acres received strychnine wheat in December, 1922. A total of 222,142 paraffin paper, ¾-ounce packages of wheat, and 1,220 pounds of loose strychnine wheat were put out. This cost about 18 cents an acre and was put out in every tenth row of cane at 10-foot intervals, making from 135 to 180 poison sets per acre. This represented 12,919 lbs. of strychnine wheat (over 6 tons), put on 3,422 acres of well-grown cane. It was applied in 16 days time and required 32 lbs. of pure strychnine alkaloid in its manufacture.

This poison work, under the direction of W. P. Naquin, the manager, has been completely supervised and carried into execution by F. R. Giddings.

## Results at Honokaa Sugar Company

What were the results? The average plantation laborer as well as skilled employee has been free in expressing his approval of the general effect. This alone cannot be used as proof of results, but the opinion of men constantly in the field is often of great value. One of the first indications of results was the complaint of trappers that very few rats could be caught. As they receive a bonus for every rat caught their difficulty seemed actual. Fewer rats were seen in the fields during harvest and in a few months' time their scarcity was obvious. This was temporary, but the rats have remained checked to the present date, two and one-half years after the commencement of the work.

Following some of the first heavy poisonings, when rats were very numerous, sufficient died in the fields to cause a perceptible odor in some localities. The laborers at times complained of this when obliged to work in these fields. Dead rats are seldom found in quantity, however, owing to their small size and very secretive ground nesting habits.

Actual proof of results required much investigation. Between January and September, 1923, the writer examined 404,100 canes in 28 fields harvested. The damage by rats was comparatively slight. An average of 4.29 per cent of the sticks showed rat injury, the worst field only being damaged to the extent of 11.9 per cent of its canes. This examination was made in all parts of each field in order that average data could be secured. Examinations by Honokaa Sugar Company in the preceding crop harvested, which was only partially poisoned,

in an experimental way, gave a damage of 18.9 per cent. During the years prior to 1922, their estimate of the amount of damage averaged from 25 per cent to 30 per cent, with some fields sometimes showing over 50 per cent damaged canes. These comparative data are sufficiently convincing. Actual monetary savings, as already discussed, of $75,000 to $100,000 annually, at a cost of about $5,000, argues well for a continuance of the campaign.

The data of Table 4 are illustrative of the results of the poison work. From the beginning of the rodent warfare in May, 1922, until the present date, over two and one-half years, fewer rats have been caught per trap per month than during all the preceding years of trapping on this plantation. From May, 1922, to January, 1925, the average number of rats caught per trap per month has been 2.33. The average number caught per trap per month for the seven years 1915 to 1921 inclusive, was 4.98. Thus trappers were able to catch over twice as many rats per trap, during all the years preceding the poisoning, as at any time since poisoning began. As they have always been given a bonus for each rat caught, their efforts have not diminished. In fact, since rats have become so checked at Honokaa, their efforts must necessarily be increased, for now only favored spots where sporadic colonies appear can be found for satisfactory trapping. This requires more work in trap manipulation than formerly, and actually, we judge, there has been considerably more than a 50 per cent reduction of rats on these plantations.

As already stated, these splendid results have been obtained and made continuous only because the poison application has been kept up as a regular daily routine of plantation work, and, we feel, the same results could be obtained elsewhere if poison were placed in quantity in the regions affected, and kept present in quantity throughout the year and the years to follow.

The results of 1924 have been satisfactory. The general system of poisoning, as adopted in 1922, has been adhered to through 1923 to 1924 and continues in 1925. As already stated, this established policy of broad poisoning as a regular part of the daily routine of plantation work, is the key to the successful results. We cannot hope to exterminate rats. There are always some left to start fresh colonies, to rapidly build up the population unless constantly checked. Their presence in cane fields is comparable to that of some hardy weed or grass whose seed is always springing up, and unless regularly destroyed soon overruns the territory occupied.

There has been no indication that rats are learning to avoid the baits. There has been no stimulated increase in rodent prolificity following large reduction, as predicted by some. At the present writing, the 1925 crop at Honokaa is being harvested. Some interesting facts are coming to light. The amount of rat damage in the cane coming to the mill shows decidedly less rat damage than in any previous crop familiar to the oldest employees of the estate. It is highly interesting to know that the first of this 1925 crop, being ground in November, 1924, showed an improvement over all previous crops to such an extent that it actually took 2 tons less of cane to the ton of sugar than for any previous November in the history of the plantation. Manager Naquin is confident that, in general, the minimum result from the rat campaign is an improvement in juice purity, or quality ratio, of at least ½ ton of cane per ton of sugar. In other

**TABLE 5**

**COMPARATIVE MILL DATA, HONOKAA SUGAR COMPANY, 1917 TO 1924, INCLUSIVE**

| | 1917 | 1918 | 1919 | 1920 | 1921 | 1922 | 1923 | 1924 |
|---|---|---|---|---|---|---|---|---|
| Loss in Molasses..... | 9.2 | 12.65 | 10.30 | 9.20 | 12.02 | 9.84 | 8.67 | 8.25 |
| Total Loss .......... | 15.2 | 18.88 | 14.88 | 15.50 | 18.39 | 14.70 | 13.34 | 12.65 |
| Total Recovery ...... | 84.8 | 81.12 | 85.12 | 84.50 | 81.61 | 85.30 | 86.66 | 87.35 |
| Boiling House Recovery ............. | 88.4 | 85.21 | 88.07 | 88.14 | 84.35 | 88.60 | 90.12 | 90.53 |

words, it is taking, on an average, at least a half ton of cane less to manufacture a ton of sugar than prior to rat control.

The improvement noted in the 1925 cane is not entirely owing to rat repression, but it is confidently believed that no such great improvement could have been possible had no rat control measures been practiced. A. Fries, Chemist of Honokaa Sugar Company, strongly confirms this contention. Table 5, showing figures compiled by him on comparative mill data for Honokaa Sugar Company for the years 1917 to 1924 inclusive, is interesting. For the two years 1923 and 1924 the cane juices show a distinct improvement over former years. Thus there is less loss in molasses and better boiling house recovery and total recovery for both years than in any preceding year. This improvement is owing to several factors, not the least of which is rat control.

These positive and excellent results from poison work at Honokaa were obtained solely with home-manufactured baits.

Many commercial rat poisons are on the market. Their expense, as compared with the home product, argues against their use. The comparative ease in their preparation, as seen from the simple formulae above given, should encourage planters in making their own mixtures. There is nothing mysterious or remarkably advantageous in the properties of the many commercial poisons advertised. We find no difference between commercial mixtures and those homemade. In fact the home preparations have been better in our experience, probably because fresh when used.

### Methods of Poison Application

Any poison bait placed in the field is necessarily exposed to many factors of deterioration. The most important is mould. As soon as this appears rats avoid the bait. This has been our general experience and it is safe to assume that poison in the field operates until it has been completely consumed or until mould appears on it. In the damp atmosphere of cane fields it is surprising how quickly most baits deteriorate. Barium carbonate cakes often become mouldy in less than a week, even though coated with paraffin. Roaches, ants, millipedes, the common ground beetle *Gonocephalum seriatum* (Boisd.) and several other minor insects attack the baits almost immediately after they are placed on the ground. The nibbling of these enables moisture to enter and mould to grow very quickly.

One of the most important improvements on rat poison baits is the scheme, conceived by W. P. Naquin, of coating the barium carbonate cakes with a thin film of paraffin and wrapping the loose grain baits in pieces of paraffined paper about 4 inches square. This greatly assists in prolonging the period of edibility

of the baits. If under average conditions a bait moulds in three days, such paraffin protection doubles this period at least. Generally such protection lasts much longer. This short prolonging of the freshness of the material means a great deal in the general result and is a marked advance in the use of poisons cast over fields on a large scale.

Much of the cake application at Honokaa can be broadcast from horseback when young cane, waste areas or pastures are treated. The entire poisoning has been done by hand at Honokaa.

During 1923, several intensive experiments were conducted at Honokaa, in fields usually having much damage, in a study of the value of covered permanent feeding spots. The results proved of interest and value. These spots were arranged at 50-foot intervals in large cane, cleared of grass, cane trash, etc., and about 1 pound of poison bait placed in a tin container at each spot, the tin being placed on its side slightly tilted up and covered with a piece of durable tarred or roofing paper about 2 feet square. The front and back edges of this rain-proof paper were folded down and the two other sides weighted down with stones. Showers and dew dripping from overhanging leaves thus have little effect upon the covered bait, except for the general increased humidity. It was soon found that rats readily entered such covered baits to feed on the protected material. Of unusual interest was the disclosed fact that only a few rats came the first night, more the second, third and fourth nights until in a week's time the maximum number seemed to visit any one of these places, which probably represented the maximum number of rats nightly foraging in the immediate vicinity, depending upon the spacing interval of the spots. This could be quite accurately determined by using non-poisoned wheat in the spots. Thus, as much poison was being nightly eaten after the sixth or seventh day as was taken, in all, during the first three or four days. More rats were finding it each night and then nightly thereafter coming to feed.

We feel, in the light of the results of such study, covering a year's investigation, that this may ultimately prove the most practical method of applying poison in cane fields and other agricultural regions operating on a large scale against rats. The 50-foot interval brought very satisfactory control. This is at the rate of about 12 to 16 spots per acre. It is very probable that a reduction of this number to about five spots per acre will be equally satisfactory, providing each place is diligently attended and the poison kept fresh when mould appears or all is eaten.

This method enables anyone in charge of the work to carefully check the men handling the poison. Any series of marked spots, which are permanent in each field, can be checked at any time. There is a great saving in poison also, because of reduced deterioration. The paper cover usually lasts through an entire season. The United States Department of Agriculture has recently recommended such a method, using small wooden covers. It is said to be a successful method in control of field mice in orchards.

Pepeekeo Sugar Company has now adopted this scheme and has reported successful results. Grove Farm Company, Ltd., has used a modification of this in the form of large bamboo pieces about 1 foot long. This was also tried at Honokaa in 1922 on a small scale, but we favor the larger tarred paper covering

over tins of poison. We have seen no indication of rats fearing or avoiding these covered spots.

Poisoning is particularly effective just after fields are harvested. Rat colonies within fields ready for harvest have their food and cover growing about them. When it is suddenly cut they must move into the nearest cover, which may be waste area, gulches or young cane fields. The heavy poisoning in such places, immediately after harvesting, has been found to be a good practice. The displaced, hungry rodents then seem to take poison baits particularly well. Trappers generally get best results at such times.

## Natural Enemies of Rats

Dogs and cats have often been used in rat warfare, but in general their effect upon rodent populations is small. They can only catch a small percentage of the overflow. On plantations in Hawaii, notably Kilauea, Honokaa and Grove Farm, they have been used. Cats in large quantity are difficult to secure and practically impossible to keep within the desired bounds in fields because of their great domesticity. Attempts to develop or procure wild domestic cats for cane fields have not been successful. A few cats about a house tend to keep some rats away, but their general effect is negligible. Dogs trained to rat catching kill many rats in cane fields at harvest time, but the percentage so killed, in comparison to the rodent population present, is necessarily quite small.

The only important natural enemy of rodents in Hawaii is the mongoose. This much maligned animal is present on all of the main islands of the Hawaiian Group but Kauai. It is a native of India and was brought to Hawaii from Jamaica, West Indies, in 1883, for the purpose of checking rats. It is a natural ratter, lives directly in the cane fields as well as out of them, with the rats, and plays a certain definite part as a control factor. Being much less prolific than rodents, it does not keep up with them sufficiently to be a "cure-all" for rats, but it helps.

During 1924, a collection was made throughout the year of mongoose excrement in cane fields at Honokaa. A total collection of 356 pellets gave interesting results. Of the total, 315 or 88.4 per cent of them contained parts of rodents, which included bones, teeth and hair. Of these a total of 186, or 52.2 per cent of the whole, contained nothing but rodent parts, the remaining 36.2 per cent containing a mixture of insect and rodent parts. The remaining 41 pellets, or 11.5 per cent of the whole, contained nothing but parts of insects. It is of high interest that nothing in any pellet was found but remains of rats, mice and insects. The insect parts determined were mostly of cockroaches. In most of those containing both rodent and insect parts, the former predominated. No feathers were found, presumably because only the blood of birds or fowls is probably taken when they are caught. We are not certain of this, however. Several mongoose burrows have been found in cane fields with feathers scattered inside and about the entrance.

We have no definite data as to just the importance of the mongoose in rodent control apart from the above, but there is no question but that it feeds extensively on rodents in the Hamakua district of Hawaii, in which Honokaa is located.

A native owl, *Asio accipitrinus sandvicensis* (Blox.), is present in the cane fields and is a good ratter, but not sufficiently numerous to be of importance. The Hawaiian hawk *Buteo solitarius* Peale, though present and probably useful, is also uncommon.

Snakes of some species are valuable natural enemies of rats and mice. None occur in Hawaii. J. C. Van Der Meer Mohr, writing of Java experiences, states that a certain species of cobra *Naja tripudians* var. *sputatrix,* which is very common in the rice fields of Bandjaratma, is said to feed solely on rats. Other species of snakes in Australia, South America, Cuba and North America are known to feed to some extent on rodents. Dr. F. X. Williams learned of a useful non-poisonous snake of British Guiana, during his recent South American trip, known as the "Yellow-tail" which was considered a very good rat-catcher. He also has referred to the "Caracara" of Ecuador, a vulture-like bird said to be useful on rodents.

## Rodier Theory of Control

A method of controlling rodents by upsetting the sex ratio in favor of the males has often been suggested and at present is vigorously championed by Wm. Rodier of Australia, who claims to have successfully applied the theory in combating rabbits in that country. This method involves the capturing of the animals alive, killing the females and liberating the males. By upsetting the sex balance sufficiently, the remaining females are said to often become barren, be less fecund and the males perhaps more cannibalistic on the young. The theory would appear to be sound and fully applies in domestic animal breeding. Fur seals of the Behring Sea have been greatly reduced through the indiscriminate killing of females, and the governments interested have found it necessary to enforce laws permitting only the killing of young males. This is said to have brought about a rapid increase in the herds.

No satisfactory method is known whereby live field rats in Hawaii can be caught in sufficient quantity to apply this theory.*

## Rats and Bubonic Plague

Bubonic plague, or the "Black Death" of medieval times, is present in Hawaii. This dreaded and fatal disease occurs now only in the Hamakua district of the island of Hawaii. Some studies have been made during 1922, 1923 and 1924 on matters relating to it and are briefly summarized here.

This plague is the same as the great plague of London in 1665, which killed over half the people who did not leave the town when it started; which devastated Europe for fifty years in the Fourteenth Century, destroying from two-thirds to three-fourths of the population in large territories, killing in all about 25,000,000 people, and which since 1896 has killed 9,000,000 humans in India alone. In 1909, it appeared in San Francisco and Seattle, was prevalent in Porto Rico in 1912 and in New Orleans in 1914. It has also levied a heavy toll on human

*By taking a small island off the coast of Oahu where rats exist and turning out a great number of males, the sex ratio could be upset and the result easily studied.

lives in Java, China, Japan and Southern Asia, and in 1924 appeared in the city of Los Angeles, California.

Plague first appeared on the island of Hawaii in Hilo in 1900, when five human cases occurred. Every year since then, excepting in 1901, 1902 and 1916, a few human cases have occurred, the worst year being in 1922 when eleven deaths occurred in the Hamakua district, six of which were at Honokaa. The small population of this Island, relative to its area, accounts in part for the small mortality. The infection now present in the Hamakua district is a constant menace to the territory, and it is hoped that the intensive poison work conducted at Honokaa will be spread into the other infected parts of the district on the other plantations, in order that the rodent population may be constantly checked and thus greatly lessen the chances of the disease spreading.

As the particular rat flea *Xenopsylla cheopis* (Rothchild), which is most responsible for the transmission of plague from rat to rat and rat to man in India and elsewhere, is the same species that commonly occurs on rats in Hawaii, we have every reason to fear the spread of this disease beyond Hamakua at any time. The same flea occurs on rats in Honolulu.

During 1923 and 1924, the fleas occurring on dogs and cats in Hamakua were investigated. The belief has long been prevalent that both dogs and cats may be responsible for occasionally carrying the rat flea into houses and thus bringing plague infection with them. Between December, 1923, and December, 1924, 2,959 fleas were taken from dogs and cats and examined individually for species determination. None of these were rat fleas. The species were as follows:

| | |
|---|---|
| From cats: | |
| *Ctenocephalus felis* (Bouché) | 411 |
| *Echidnophaga gallinacea* (Westwood) | 4 |
| From dogs: | |
| *Pulex irritans* Linn. | 636 |
| *Ctenocephalus felis* | 1879 |
| *Echidnophaga gallinacea* | 17 |

As these dogs and cats lived on the plantation where the rat studies were made they must be exposed to rat fleas frequently, particularly when in the cane fields during harvest and in dry weather when fleas are most abundant. We judge from the results of these examinations that rat fleas are not commonly carried by dogs or cats. It should be noted that the common flea carried by dogs and cats was the human or house flea, *Pulex irritans,* and the cat flea, *Ctenocephalus felis,* with a few chicken fleas, *Echidnophaga gallinacea.* The determinations of these fleas were made by H. E. Ewing, U. S. Bureau of Entomology, who states that the presence of the cat flea on dogs and the absence of the dog flea corresponds with the situation in many places in Eastern Asia and Polynesia, where the dog flea is absent but the cat flea present.

Of interest is the fact that only one species of rat flea has been taken from rats on Hawaii and this one is the true plague flea. Several other species of fleas occur on rats elsewhere. One rat flea was taken from a mongoose at Honokaa.

The mouse flea *Ctenopsyllus musculi* (Dugés) is common on mice in Hamakua.

Fleas are not common on rats in Hamakua except during dry spells extending for many weeks or several months. This explains the appearance of plague amongst the rats during dry weather. During the entire period of rat investigation, covering two and one-half years, live rats have been caught in the fields and brought indoors for experiment. These have always been examined for fleas. It was soon noted that during rainy seasons very few rats had any fleas at all, and then usually only one or two, though a blood-sucking mite, *Laelaps* sp., is nearly always present. During long, dry spells, however, the rats commonly carried fleas, the greatest number taken from any one rat being 32, all of which were of the species *Xenopsylla cheopis,* the plague flea. No doubt they often bear many more fleas than this. As wet conditions are definitely known to be highly unfavorable to flea development, owing mostly to mortality among their eggs and larvae in wet soil, this scarcity of fleas on the rats is readily understood during wet weather. As the rat flea, and particularly this species occurring on rats in Hawaii and elsewhere, has been shown to be the prime transmitter of plague from rat to rat and rat to man, we can fully anticipate plague outbreaks in dry weather and particularly during long periods of drought, as Hamakua sometimes experiences.

An examination of the recorded data compiled by the Territorial Board of Health, on the occurrence of rodent plague on Hawaii during its entire history, correlated with the records of rainfall, amply bears out this statement. From these data we have considerable proof of the theory and can with fair precision predict the appearance of plague and the danger period for human infection.

This study of rainfall and rodent plague data for the years 1912 to 1919, inclusive, in Hamakua, is interesting. Using the precipitation at Honokaa Sugar Company as an average for the district, we find in 1912 under a rainfall of 54.7 inches, which is moderately dry, a total of 80 plague rats were caught. The following year (1913) being slightly wetter (62.5 inches) brought 16 plague rats in the examinations. Then in 1914 rain was heavy (141.6 inches) and only 3 plague rats were found. The year 1915 had only a moderate rainfall and we find an increase in the number of infected rats taken, totalling 12. In 1916, more rain fell (86.1 inches) than in 1915, and a drop came again in the number of plague rats caught, when only 6 were found. Then in 1917, a year of unusual drought (26.1 inches), 22 plague rats were diagnosed; and this was immediately followed by a very wet year (1918) with 157.5 inches of rain, when only 3 such rats were found. Then followed another dry year (1919) with only 40.5 inches, and once more the curve of plague infection rose and 19 plague rats were caught. There are one or two anomalous years between 1900 and 1924 which are not in complete accord with our contention, but, in general, dry years show distinct increases in rodent plague infection and wet years the reverse.

This prevalence of plague during dry weather and its comparative scarcity in wet seasons has already been recognized by the Territorial Board of Health. We believe that, in part, it explains how plague gradually left the wet Hilo district of Hawaii, where it started in 1900, and worked out into the drier rat-infested Hamakua district where climatic conditions are more favorable for flea development. It is known in India that plague thrives in a climate with temperature medium between intense heat and moderate coolness, between very wet districts

and excessively dry regions. Hamakua would seem to have the happy medium of these conditions which is favorable to flea development during the dry seasons.

It is believed that the continuance of the rat poisoning at Honokaa will considerably alleviate the plague menace there, and the more widely the poisoning is extended in the district of Hamakua the better will become the chances for plague eradication there. The fewer rats present, the less chances occasional infected individual rats will have to pass the disease on in the particular locality where it may be. Infected foci will become reduced, for without rats present, almost immediately to pick up fleas from other rats sick or dying from plague, the disease must necessarily die out in those spots in a very short time, for the life of the flea is short without fresh blood for food, and the life of the plague bacillus is also comparatively short outside its living host.

When plague appeared in San Francisco in 1900, over a million rats were destroyed by trapping in six months' time, which was followed by a disappearance of the disease. It gained access, however, to the ground squirrels in certain parts of California, which exaggerated the difficulty. The disease was brought under control, however, after the killing by trapping and poisoning of over 20,000,000 squirrels. It was not eradicated from the squirrels, but was evidently very greatly checked, for the extent of human mortality was slight.

We quote in conclusion an interesting statement by Richard H. Creel, Past Assistant Surgeon, U. S. Public Health and Marine Hospital Service, which has a direct bearing on the subject of plague eradication in Hamakua. In a paper entitled *Rat Proofing as an Antiplague Measure*, 1910, he states:

The total eradication of rats in a locality is not absolutely necessary, however, to the eradication of plague. If the rat population is kept within fairly low limits, rat centers destroyed, and such rat population as does exist well scattered and not congested, it is ventured that rat plague will disappear from a locality. Plague among rats in San Francisco ceased to appear when the number of rodents was reduced some 50 per cent, but such reduction was accomplished only after six months of ceaseless endeavor, which included also the rat-proofing of the bakeries, stables and markets in the city.

It is a logical supposition that close contact is just as essential for the propagation of plague among rats as it is for the spread of certain communicable diseases among human beings, the increase of cases being in direct proportion to the density of population and closeness of contact.